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THE USE OF NOVEL SPECIMEN DESIGNS IN RECIPROCATING LINE CONTACT TESTS

Tribotesting 1

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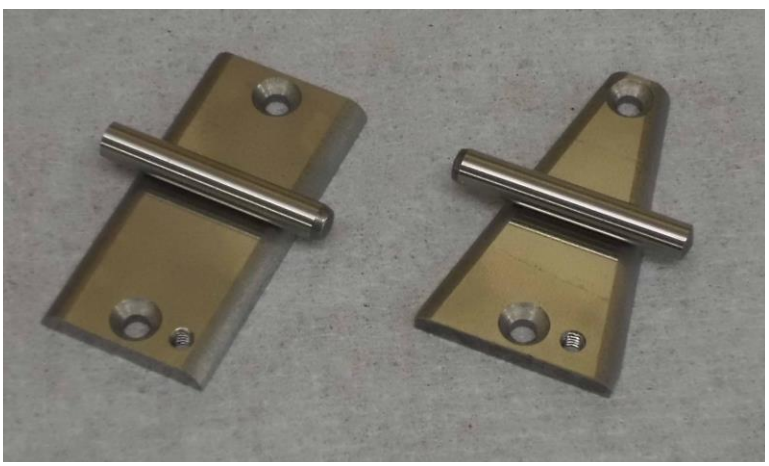
INTRODUCTION

The tribological advantage of a reciprocating line contact over a reciprocating hertzian point contact test is that it allows tests to be performed with wear and wear transitions propagated at an asperity level. By contrast, tests involving a sliding hertzian point contact invariably result in the destruction of the surface topography, at the very start of the test. If the test starts with severe adhesive wear it cannot subsequently be used to investigate mild wear or transitions to more severe regimes. The current work focuses on experiments with line contacts with plate specimens with curved edges, both parallel and non-parallel, and explores techniques for increasing the information content of each test.

LINE CONTACT SPECIMENS

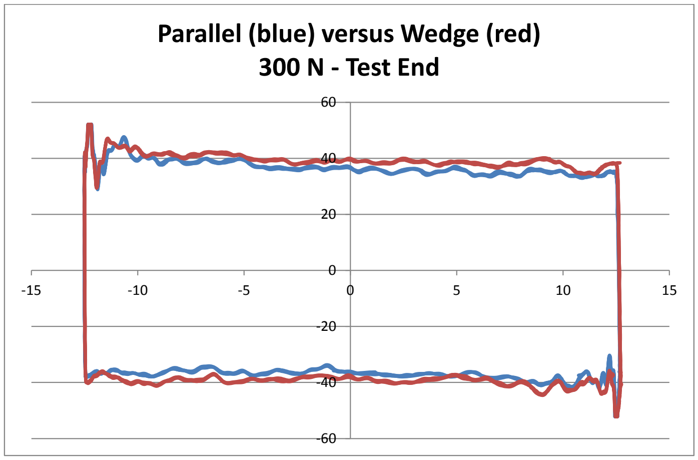
One of the key issues with a simple line contact specimen is how to mitigate the stress concentration at either end of a cylindrical specimen, of finite width. One solution is to use a logarithmic end profile. Another solution is to use a plate specimen with curved edges and a cylinder that is wider than the plate. This then allows the possibility of using plate specimens with non-parallel sides, such that the contact pressure varies with stroke position.



Curved edge specimens

A series of tests on parallel and wedge shaped specimens were performed, under a range of different test conditions, with interesting results.

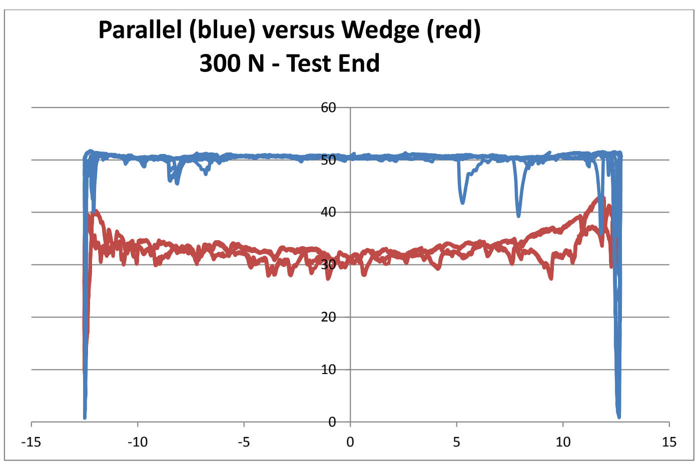
TESTS WITH PAO 4



Instantaneous friction signal – steady state conditions – PAO 4

Although there were differences in behavior during the running-in process and at various points during the test, high speed data at the end of the test showed that the frictional behavior of the two different sample geometries was essentially the same. Hence one can conclude that, under these conditions, Amontons' 2^{nd} Law of Friction, which states that friction is independent of the apparent area of contact, applies.

However, high speed electrical contact resistance data indicated a more continuous film with the parallel specimen, compared with the wedge specimen, suggesting a higher level of asperity interaction with the latter.



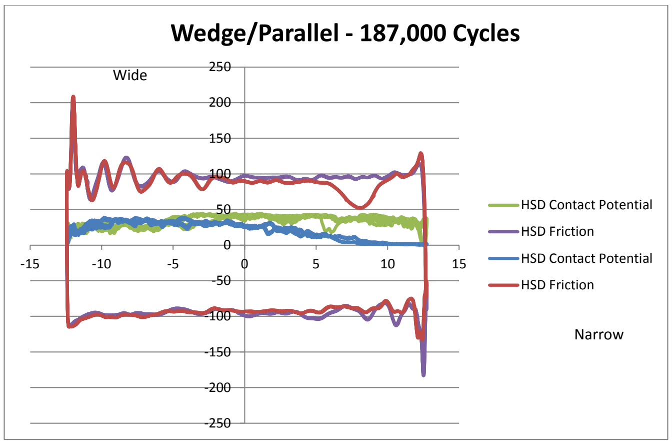
Contact potential signal – steady state conditions – PAO 4

Profilometry measurement of the worn plates indicated that the wedge specimens produced approximately 20% greater maximum wear depth than the parallel specimens. In the parallel sample tests, all points across the pin sample are subjected to the same sliding distance. The middle section of the pin in the wedge sample tests is also subjected to the same sliding distance, but double the contact pressure at one end of the stroke. The result in this case is approximately 50% greater wear depth over the middle section of the pin. This experiment demonstrates that there is no simple connection between friction and wear.

Test with Fully Formulated Lubricant

A series of tests were run with ramped loads and temperatures and with differential heating of the plate specimens (one end hotter than the other), to establish whether the wedge specimens could be made to scuff, preferentially, at the narrow end, in other words, at the position of maximum contact pressure. Finally, tests were run at constant load and temperature to see if scuffing could be produced simply by running for a large number of cycles, in other words, without attempting to precipitate failure by additional external means, such as ramping the load, ramping the temperature or starving the lubrication.

Comparison between the low speed data traces indicated that there is little difference between the r.m.s. friction traces for the parallel and wedge samples. Instantaneous friction traces show that, as with previous experiments, there is little difference between the frictional response of the parallel and wedge samples. However, there is a difference with contact potential, which collapses at the narrow end of the wedge specimen.



Green/Blue: Parallel – Purple/Red: Wedge

As further cycles are accumulated, the collapse of the contact potential signal at the narrow end of the wedge becomes more apparent and there is localized divergence between the friction traces, at this point.

Conclusions

Provided that the wear mechanism is the same at either end of a wedge specimen, the friction appears to be independent of nominal contact area.

Time smoothed friction provides little information with regard to wear transitions under mild regimes.

Instantaneous contact resistance appears to correlate with wear transitions.

With a wedge specimen it is possible:

- To generate different wear regimes at either end of the specimen, hence providing more information from a single test run.
- To produce mild scuffing, while running under conditions of steady load and temperature, in other words, without resorting to the application of ramped loads or temperatures.

KEYWORDS

Adhesive Wear - Boundary Lubrication - Lubricated Wear – Scuffing - Sliding Line Contact - Wear Transitions

The use of novel specimen designs in reciprocating line contact tests

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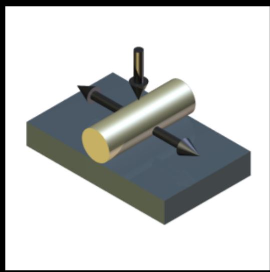
Introduction

- Limitations of sliding hertzian point contact tests as model of real-world contacts
- Advantages of a line contact over a hertzian point contact test
- Techniques for increasing the information content of each test
- Bench-mark tests that typically produce no more than about 10 microns linear wear

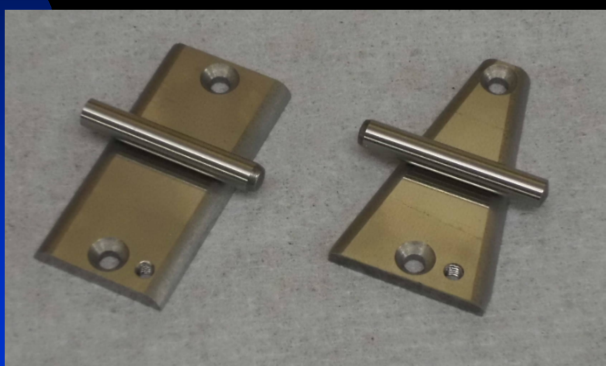
Curved edge specimens

How to mitigate geometric stress concentration?



Curved edge specimens

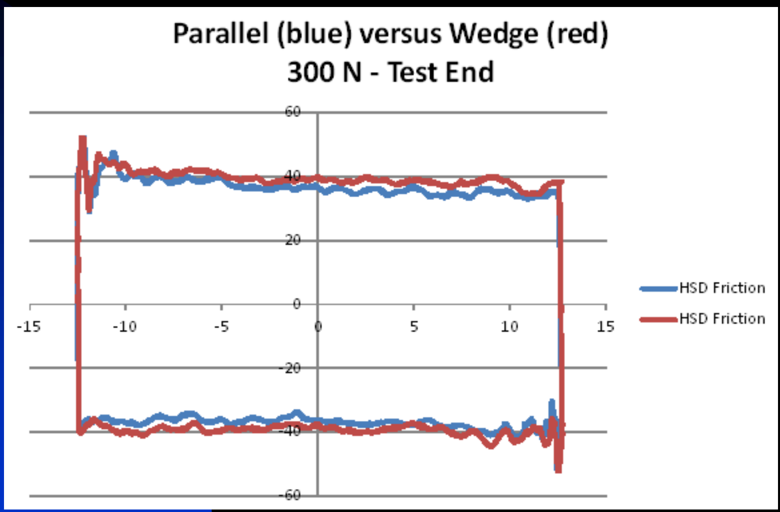
How to mitigate geometric stress concentration?



Experiment 1: Friction and Wear Comparison

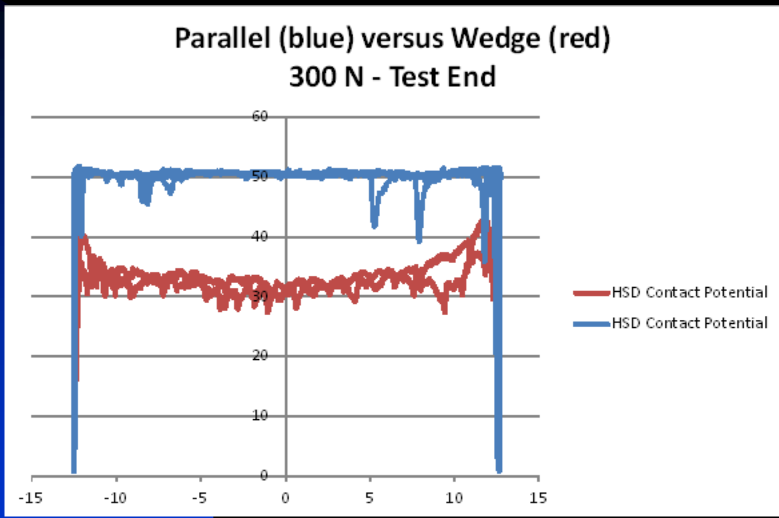
- Tests to explore the difference in behaviour of parallel and wedge specimens, under steady state conditions
  - Moving specimens: 6 mm diameter hardened/ground pin
  - Plate specimens: cast iron flat – parallel or wedge
  - Lubricant: PAO 4
  - Stroke: 25 mm
  - Frequency: 10 Hz
  - Load: 300 N (after running in at 50 N)
  - Temperature: 100 C
  - Duration: 100,000 cycles

Experiment 1: Friction and Wear Comparison



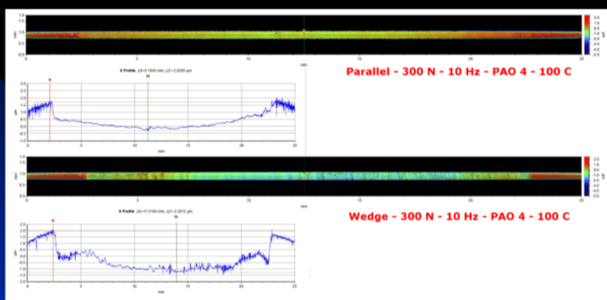
Amontons' 2nd Law: Friction independent of apparent area of contact

Experiment 1: Friction and Wear Comparison



More continuous film with parallel compared with the wedge

Experiment 1: Friction and Wear Comparison



Wedge specimens approximately 20% greater maximum wear depth than parallel specimens

Plate wear produced essentially too small to indicate a definitive difference in wear between different regions on wedge specimens

Identifiable differences between wear of pins

Experiment 1: Friction and Wear Comparison

No simple connection between friction and wear

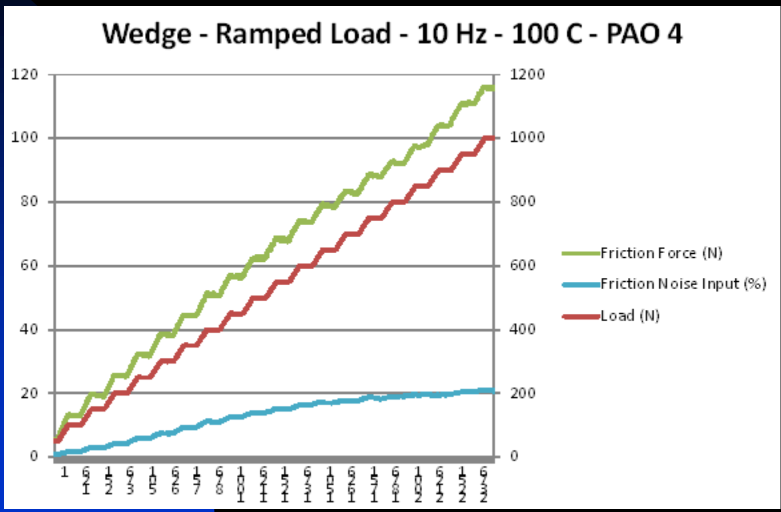
Friction and wear essentially "de-coupled"

Experiment 2: Scuffing Test

- Tests to see if wedge sample, when subjected to ramped load, would preferentially scuff at the narrow end

– Moving specimens:	6 mm diameter hardened/ground pin
– Plate specimens:	cast iron flat – wedge
– Lubricant:	PAO 4
– Stroke:	25 mm
– Frequency:	10 Hz
– Load:	Load ramped in 100 N steps to 1000 N
– Temperature:	100 C
– Duration:	34,000 cycles

Experiment 2: Scuffing Test



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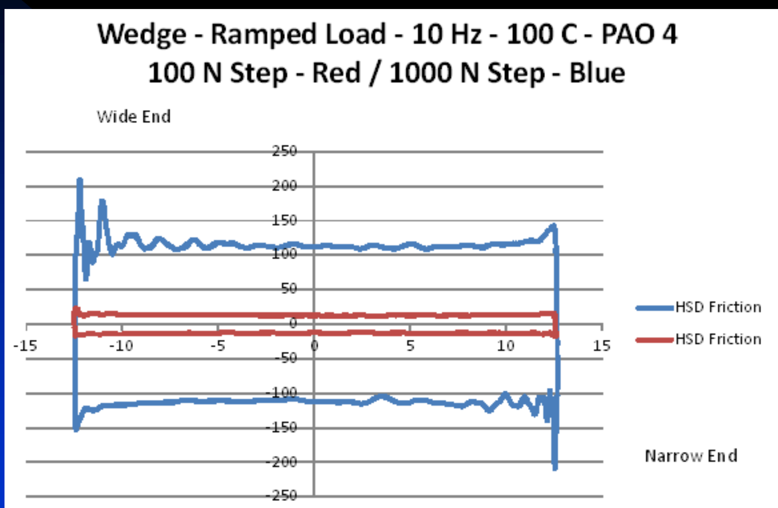
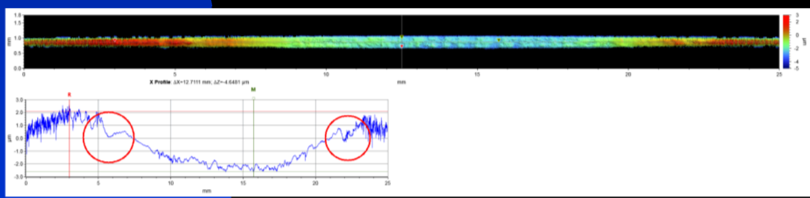


Experiment 2: Scuffing Test

- Changing contact width, hence changing contact pressure, has no effect on friction, hence Amontons' 2nd Law applies
- Contrary to expectations, in experiment with PAO 4 as the test fluid, scuffing does not appear to initiate at the high pressure, narrow, end of wedge specimen
- Pin samples suggest scuffing initiates at the extreme ends of contact and progresses inwards towards centre



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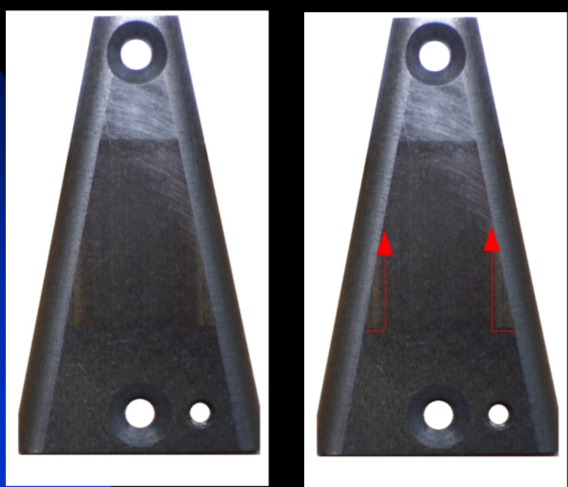


Experiment 3: Differential Heating

- Tests to see if combination of higher contact pressure and higher temperature could precipitate a scuffing type failure
  - Moving specimens: 6 mm diameter hardened/ground pin
  - Plate specimens: cast iron flat – parallel or wedge
  - Lubricant: PAO 4 and fully formulated lubricant
  - Stroke: 25 mm
  - Frequency: 10 Hz
  - Load: 300 N (after running in at 50 N)
  - Temperature: 30 to 180 C (continuous ramp)
  - Duration: 9,000 cycles

Experiment 3: Differential Heating

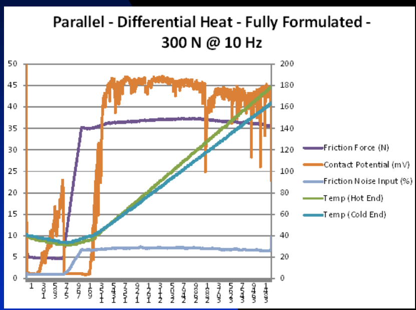
Experiment used modified specimen bath and heating arrangement, such that plate specimen was only heated from one end

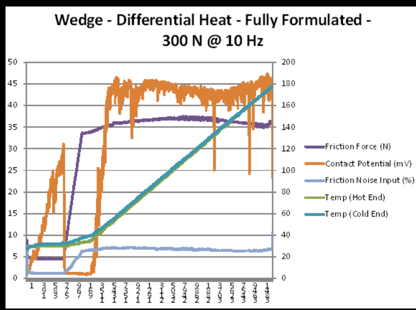
Thermocouples attached to each end in order to monitor the temperatures

Lubricant was drip fed at cold end of specimens

Wedge specimens heated at narrow end so lubricated at wide end

Experiment 3: Differential Heating





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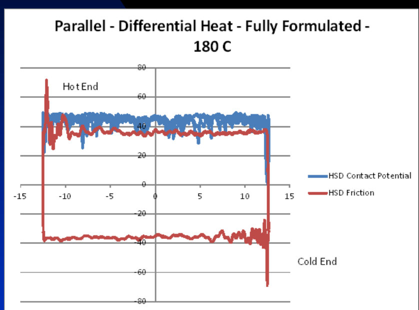
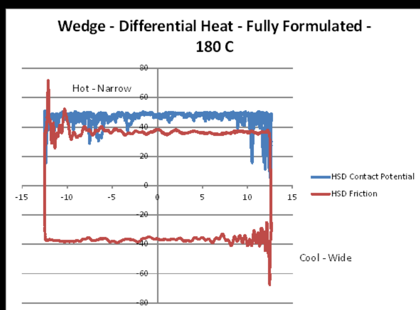




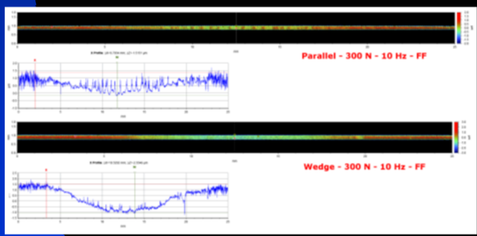
Experiment 3: Differential Heating

Tests did not generate the target behaviour

With fully formulated oil and this experimental procedure, there is minimal difference between response of parallel and wedge specimens in terms of r.m.s. and instantaneous friction and contact resistance

There is a difference in wear of pin specimens

With wedge specimen and fully formulated lubricant, scuffing at pin ends is supressed, indicating that, under low entrainment conditions at pin ends, boundary lubricant additives protect surfaces



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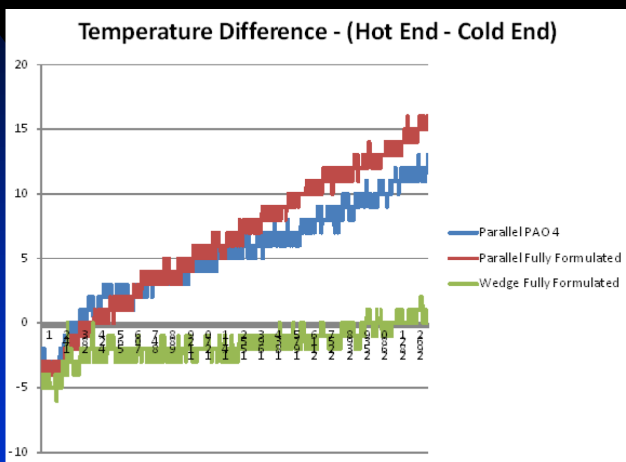


Unexplained behaviour – more frictional heating with wedge?

Experiment 4: Endurance - High Load

- Tests to see whether wedge specimens, with fully formulated lubricant, at constant load and temperature, would preferentially scuff at narrow end

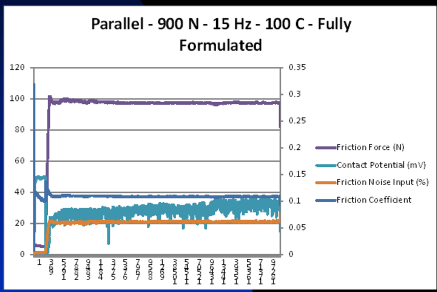
  - Moving specimens: 6 mm diameter hardened/ground pin
  - Plate specimens: cast iron flat – parallel or wedge
  - Lubricant: fully formulated lubricant
  - Stroke: 25 mm
  - Frequency: 15 Hz
  - Load: 900 N (after running in at 50 N)
  - Temperature: 100 C
  - Duration: 288,600 cycles (including running-in)

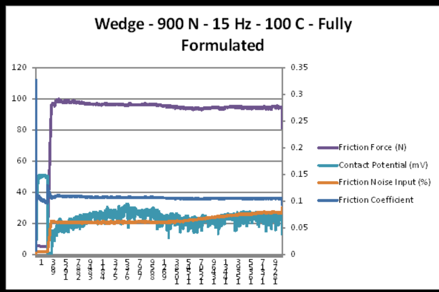
Experiment 4: Endurance - High Load

Attempt to precipitate failure without using additional external means, such as:

- 1. Ramping load
- 2. Ramping temperature
- 3. Starving lubrication

Experiment 4: Endurance - High Load





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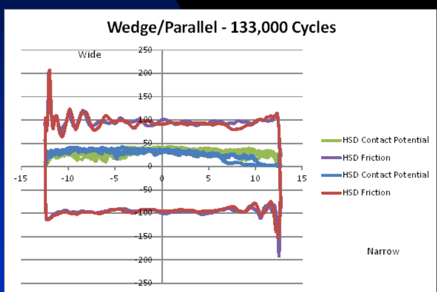
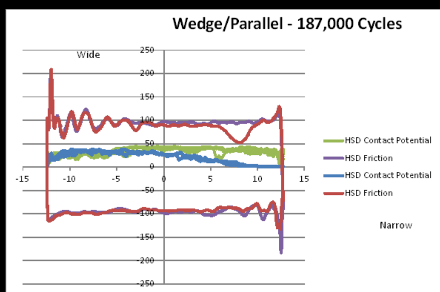
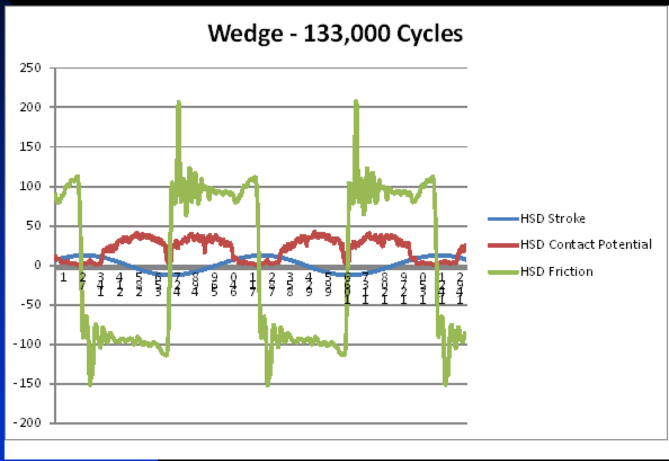




Green/Blue: Parallel – Purple/Red: Wedge

Experiment 4: Endurance - High Load



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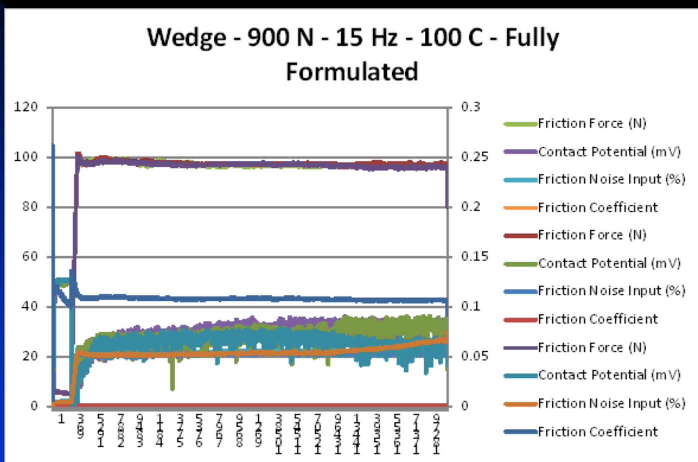


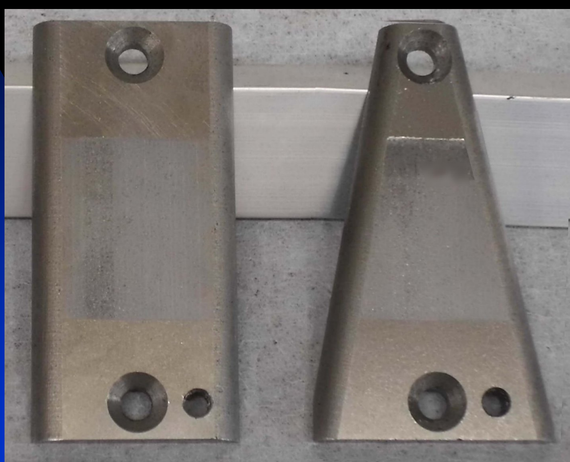
Repeatability – Wedge Specimens x 3

Experiment 4: Endurance - High Load

Comparing the low speed data for three wedge specimen tests indicates a degree of repeatability far exceeding that normally observed with line contacts tests.

Although, at this stage, one can only speculate with regard to the causes, it may be that with line contact tests where the contact width (or pin length) is less than the plate width, edge effects have an important influence on frictional response and subsequent repeatability. With curved edge plate specimens and overlapping pin samples, these (indeterminate) effects may be avoided.

Experiment 4: Endurance - High Load



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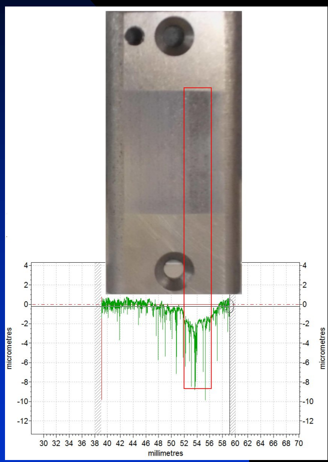

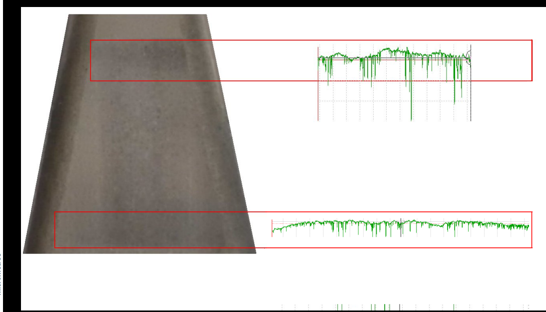

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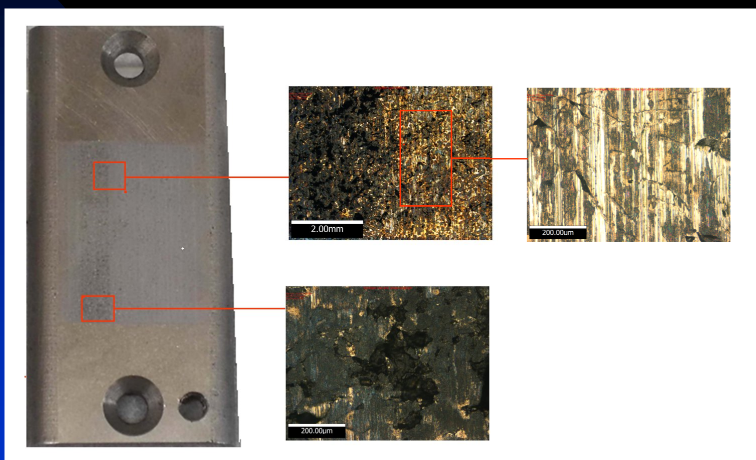
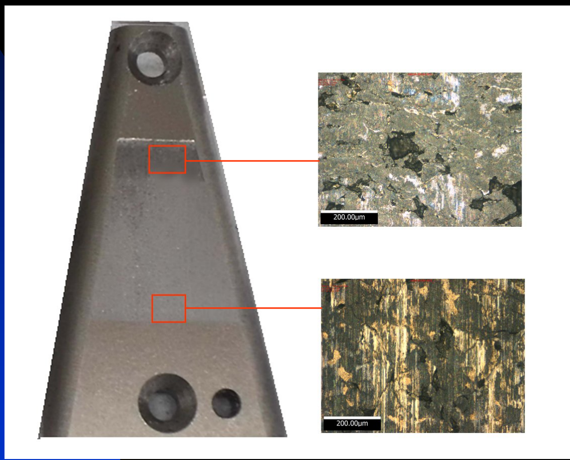


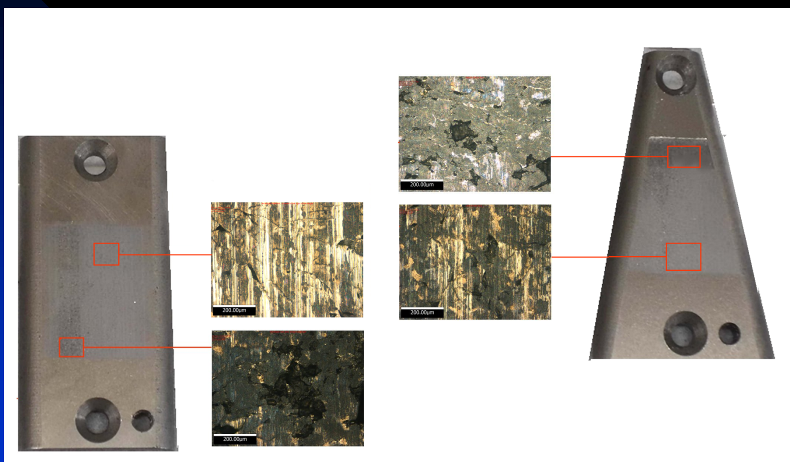
Both reversal positions indicate "severe adhesive wear", characterised by deep holes in surface
Lighter regions outside these areas have cracks in surface, suggesting "mild adhesive wear"

Experiment 4: Endurance - High Load



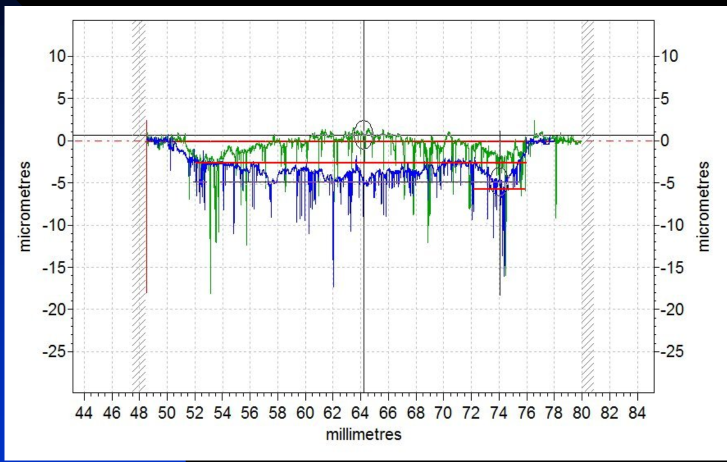
Wide end reversal position indicates “mild adhesive wear” with characteristic directionality
Narrow end: “severe adhesive wear” with destruction of oxide/additive film & plastic deformation

Experiment 4: Endurance - High Load



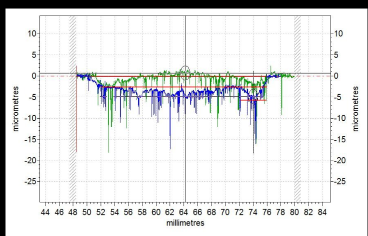
Is this “mild” and “severe” scuffing?

Experiment 4: Endurance - High Load



Parallel – Green / Wedge - Blue

Experiment 4: Endurance - High Load

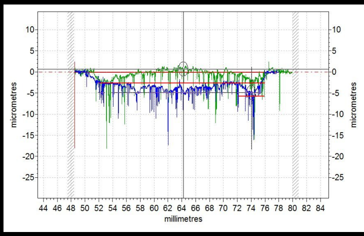


Stroke ends:

Parallel: wear same at each end

Wedge: wear same at wide end as parallel
wear double at narrow end

Experiment 4: Endurance - High Load



Mid-stroke:

Parallel: little wear

Wedge: significant wear
does ramping contact pressure
destroy lubricant additive film?

Conclusions

There is a risk associated with using a non-additive fluid when developing a test procedure to model boundary lubricated contacts

Repeatability with curved edge plate specimens and overlapping pin samples appears to be good, compared with tests where the contact width is less than the plate width. This suggests that in the latter case, variable edge effects may have an important influence on repeatability

Conclusions

Provided that the wear mechanism is the same at either end of a wedge specimen, the friction appears to be independent of nominal contact area

Time smoothed friction provides little information with regard to wear transitions under mild regimes

Instantaneous contact resistance appears to correlate with wear transitions

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With a curved edge wedge specimen it is possible:

to generate different wear regimes at either end of the specimen, hence providing more information from a single test run

to produce mild and severe adhesive wear, while running under conditions of steady load and temperature, in other words, without resorting to the application of ramped loads or temperatures

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